EFFECTS OF TOOL PATH STRATEGIES ON SURFACE ROUGHNESS IN HIGH SPEED MILLING

ABDUL RASHID BIN MUHAMMAD

Report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Manufacturing Engineering.

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

ABSTRACT

In this project, two type of tool path strategies have been selected which are helical and back and forth tool path in order to determine the effects of both tool path strategies on surface roughness. The effects of the feed rate, cutting speed, and depth of cut on surface roughness were determined. Taguchi method was employed in order to optimize the machining parameters. The optimum machining parameter combination was determined by using analysis of signal-to-noise (S/N) ratio. The impact of the machining parameters on the surface roughness was determined by the use of analysis of variance (ANOVA). Measurement of surface roughness has indicated that helical has lowest surface roughness compare to back and forth tool path. Results from ANOVA also proved that helical tool path has significant impact on surface roughness. Furthermore, S/N ratio shows that each type of tool path has different combination of optimum machining parameters. From this project, it has been learned that helical tool path is better cutting tool path to be used in machining operation. This project would help engineer and machinist to select the best pocketing tool path for their product.

ABSTRAK

Di dalam projek ini, dua jenis cara laluan pemesinan mata alat telah dipilih iaitu 'helical' dan 'back and forth' supaya dapat menentukan kesan kedua-dua cara laluan pemotongan ke atas kekasaran permukaan. Kesan kadar suapan, kelajuan pemesinan dan kedalaman pemotongan telah ditentukan. Kaedah Taguchi telah digunapakai untuk mencari parameter pemesinan yang optimal. Parameter pemesinan yang optimal telah di cari menggunakan nisbah 'signal-to-noise' (S/N). Impak parameter pemesinan juga telah dikaji menggunakan 'analysis of variance' (ANOVA). Pengukuran kekasaran permukaan telah menunjukkan bahawa cara pemotongan 'helical' mempunyai nilai kekasaran yang terendah berbanding cara pemotongan 'back and forth'. Keputusan dari ANOVA juga membuktikan bahawa cara pemotongan 'helical' mempunyai kesan yang ketara ke atas kekasaran permukaan. Daripada projek ini, cara pemotongan 'helical' adalah terbaik dan sesuai digunakan semasa operasi pemesinan. Kerana ini, projek ini akan membantu jurutera dan pengendali mesin untuk memilih cara pemotongan yang sesuai bagi menghasilkan produk mereka.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

V_c	Cutting speed
a_p	Percentage of the cutter diameter
a_e	Percentage of the cutter diameter
f_z	Feed rate per tooth
R	Roughing
F	Finishing
R_a	Average surface roughness
R_q	Root-mean-square roughness
SN	Signal-to-noise
n	Number of observations
$\bar{y}$	Mean of observed data
s_y^2	Variance of y
y	Observed data
A	Feed rate (mm/min)
B	Cutting speed (rpm)
C	Depth of cut (mm)
C %	Carbon (percentage)
Si %	Silicon (percentage)
Mn %	Manganese (percentage)
Cr %	Chromium (percentage)
Mo %	Molybdenum (percentage)

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION OF THE PROJECT

Generally, this project would give benefit to manufacturing industry especially for tool and die making industry. This is because this project would help manufacturing engineer and machinist to select best pocketing tool path strategy with given optimal machining parameters. The pocketing tool path strategy and machining parameters are defined in Computer Aided Manufacturing (CAM) software such as CATIA and Mastercam in order to produce machining program.

The result from this project would help engineer and machinist to produce machining program which produce best surface finish so that they can reduce time to fabricate the part or product. Usually, they used try and error method to determine best machining parameters where this method consumed much time and cost.

This project is expected to obtain result from the experiments which utilized Taguchi design of experiment. The experiments are based on given machining parameters which consist of three levels. Machining parameters used in the experiments are cutting speed, feed rate and depth of cut. All these parameters are specified into three levels which are low, medium and high.

Then, the value of surface roughness of determined machining parameters are checked to gain the result. The result is then compared with specified pocketing tool path strategy in order to determine best surface roughness and optimal machining parameters.

1.2 BACKGROUND OF THE PROJECT

Nowadays, high speed machining method is applied extensively in manufacturing industry. This is because high speed machining can improve surface quality of the product and also decrease machining cycle time with high efficiency if compare to conventional method. One of its major applications is to produce tool and die for plastic injection moulding. Others applications of high speed machining such as to make components for aeronautical and automotive, biomechanical and medical products and also electrical and electronic devices. The advantages of high speed machining are it is able to produce the product with high efficiency, accuracy and also quality.

Surface roughness is one of important aspect when to determine quality of the product. It is because surface roughness may affect some of properties of the product such as friction, wear, fatigue and others. There are many factors that contributed to surface roughness such as machining parameters, material of the workpiece and cutting tools, lubrication fluids and others. Another application of surface roughness is to check performance of the machine and cutting tool.

Taguchi method design of experiment is a method which used optimization of machining parameters in order to obtain high quality product, efficient process and decrease the manufacturing cost. Compare to other design of experiment method, Taguchi method is much easy to perform and not complex to understand. In this project, this method is used to find optimal machining parameters with good surface roughness which is confirmed by signal-to-noise (S/N) ratio and also analysis of variance (ANOVA).

Commonly, P20 is pre-hardened steel is a material used to produce tool and die making industry such as to make mould components and inserts. Other than that, it is also used to produce tool and die in die casting process. It is a chrome-moly alloy with carbon content of 0.4% and thermal conductivity of P20 is 29.0 w/(m °K).

Many experiments have been made in order to investigate surface roughness in high speed machining. Some of the researches investigate the effect of material or machining parameters on surface roughness while others investigate relation between material of workpiece and surface roughness. It is essential to determine on how to obtain optimal machining parameters and strategy that will help to minimize machining time and cost.

1.3 PROBLEM STATEMENT

Pocketing is a machining operation used to produce pocket whether it is open pocket or close pocket. This machining operation is commonly used in tool and die making industry to produce inserts or tool and die components. Other than that, pocketing also used to produce profiles depend on the geometry of the product.

Normally, pocketing machining operation leaves cutter mark which is depend on the machining parameters and tool diameter. The cutter mark leaved by this machining operation also depends by the selected pocketing tool path strategy defined in CAM software. Usually, there are five types of tool path strategies provided in CAM software such as helical, back and forth, spiral and others.

Because of that, the purpose of this project is to determine the effect of different pocketing tool path strategy on surface roughness of machined surface. This project utilized Taguchi method design of experiment which is designed according to specified machining parameters and levels.

1.4 OBJECTIVES OF THE PROJECT

There are three main objectives of this project which are:

- **To study effect of tool path strategies on surface roughness.**
  The experiments were performed by using specified machining parameters such as feed rate, cutting speed and depth of cut. These parameters used are divided by three levels which are low, medium and high. After the

machining process is done, the surface of the machined surface are checked using surface roughness tester to determine the effect.

- **To analyze data obtain from the experiment.**
  After the experiments were done, data from the experiments were analyzed using signal-to-noise (S/N) ratio and analysis of variance (ANOVA) to determined optimal machining parameters which can produce good surface roughness.

- **To decide which tool path strategy results optimal surface roughness.**
  After the result is analyzed, then the result for tool path is compared with each other to determine which tool path can produce optimal machining parameters.

1.5 SCOPES OF THE PROJECT

The scopes of the project include:

- **Different type of tool path strategy.**
  Selection of two different type of tool path cutting movement in machining parameter defined in CAD/CAM software which are helical and back and forth.

- **Machining parameters.**
  To used three machining parameters which are feed rate, cutting speed and depth of cut in order to determine optimal machining cutting for these parameters.

- **Machining conditions.**
  To use three levels of machining parameters conditions which are low, medium and high.

1.6 REPORT ORGANIZATION

In this project report, it is consists of five main chapters which is to explain specific information according to each chapter. Contents of all the chapters are arranged systematically in order to make this report more understandable and clear.

- **Chapter 1: Introduction**
  In this chapter, information displayed is the background, problem statement, objectives, scopes and others. This chapter is important because it used to introduce the specific problem which is lead to realization of this project.

- **Chapter 2: Literature Review**
  Detail information about this project is written in this chapter. Some of the information is about high speed machining, surface roughness, material used in this project and others.

- **Chapter 3: Methodology**
  Design of experiment is presented in this chapter. It gives details about the experiment that has been carried out so that data can be obtained for analysis process.

- **Chapter 4: Results and Discussions**
  Presented results from the experiment which illustrate in terms of tables and graphs. Also, details about data analysis are given in order to explain how the results are analyzed and compared.

- **Chapter 5: Conclusion and Recommendations**
  Presented conclusion of the project and determine whether the objectives of the project are achieved or not. Then, recommendation for further research also suggested in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 HIGH SPEED MACHINING

2.1.1 Definition

High speed machining (HSM) is the machining process that has many advantages compare to the conventional machining process such as able to produce high quality parts, increase productivity rate and high accuracy. Because of that, this machine is used widely in the industry, for example in tool and die making industry and to make components for aviation industry (Ekanayake and Mathew, 2007).

In 1931, Carl Solomon introduced the first concept of High Speed Machining where in his experiments he found that when cutting speed is increase, the cutting temperature increases up to a maximum value close to the melting point of the material and then the temperature is decreases with further increase in speed. This concept is shown in Figure 2.1 where temperature of the material is decrease when the cutting speed used is higher (Ekanayake and Mathew, 2007 and Pasko et al. 2002).

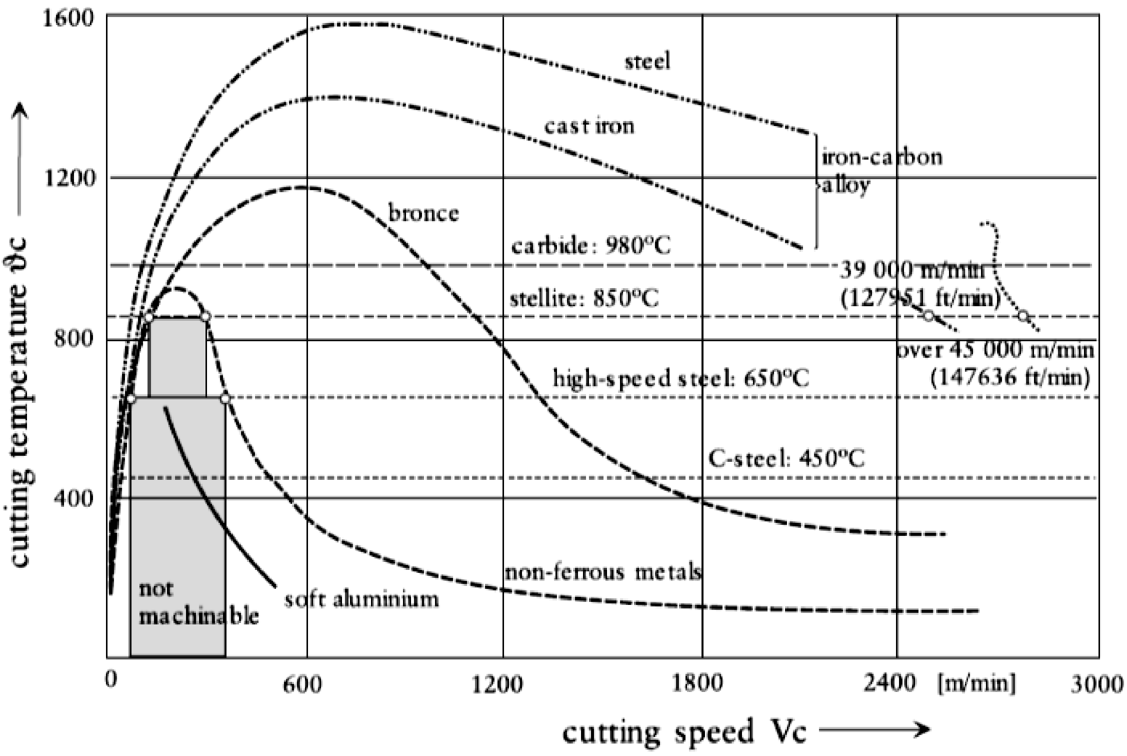

Figure 2.1 Cutting temperature vs. cutting speed

Source: Schulz (1999)

Ekanayake and Mathew (2007) have explained that high speed machining can be defined as a machining process that used higher speeds or higher feed rates while the depth of cut is smaller compare to the conventional machine. Thus, the chip produced by this process is small and the chip formation is much complex.

But Pasko et al. (2002) have stated that high speed machining is not only defined as high cutting speed but also high rotational speed machining, high feed machining and others. Pasko et al also referred this machining process as the operations which are carried out with special methods and equipment.

Schulz and Moriwaki (1992) explained that high speed machining is difficult to be defined because actual cutting speed achieved is influence by some factors such as material of the workpiece, the type of machining operation, cutting tool used in the machining operation and others. Because of that, there are many ways to define high speed machining which depends on some factors. For example in Figure 2.2, it shows that the range of cutting speed changes according to material of the workpiece.

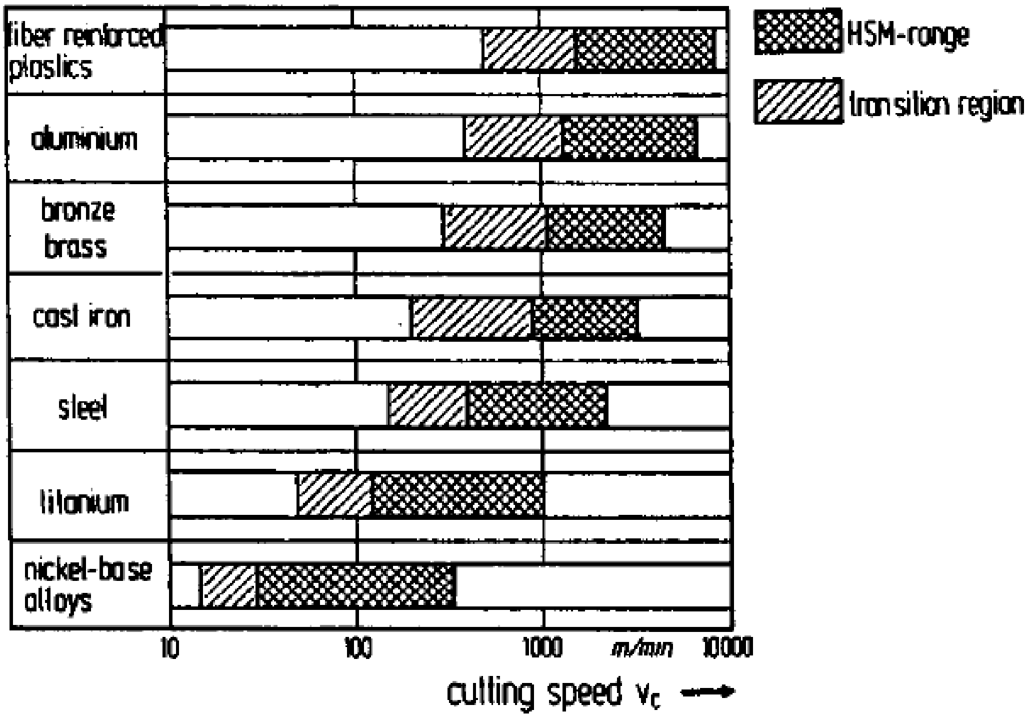

Figure 2.2 HSM cutting speed based on material

Source: Schulz and Moriwaki (1992)

2.1.2 Advantages

It has been known that high speed machining has many advantages compare to conventional machining process. Some of the advantages are this machining process able to produce high quality parts, increase productivity rates and also high accuracy. Other advantages of high speed machining are (Sandvik Coromant, 1999):

- Cutting tool life and durability can be increased.
- Shorten engagement time for the cutting edge.
- Minimum and constant tool deflection.
- Low radial forces on the tool and spindle.
- Low impact on the spindle bearing.

- Longer tools can be used without risk for vibration.
- Reduced cost when the machining process produces low material removal.
- Good surface finish can be achieved and thus minimize manual polishing process.
- Able to machine very thin walls.
- Produce accurate dimension and shape.
- Manual polishing process can be minimized because the machine able to produce good surface finish.

2.1.3 Disadvantages

Although, high speed machining is able to have many advantages in its application, at the same time it is also have some disadvantages. Some of disadvantages of high speed machining including (Sandvik Coromant, 1999):

- Guide ways, ball screws and spindle bearing wear in short of period.
- Expensive and higher maintenance cost.
- Need special knowledge about the process, programming, and interface.
- Skilled human resource with knowledge in high speed machining is hard to find and recruit.
- Longer period of trial and error process.
- Bigger consequences if mistake and errors occurred.
- Necessary to have good work and process planning.
- High precautions are compulsory when operating the machine.

2.1.4 Cutting Tools

There are four important criteria of cutting tools in high speed machining which are cutting alloy, cutting edge geometry, design and the interface between tool and machine spindle (Schulz and Moriwaki, 1992).

- **Cutting alloys**

  It is very important to know wear processes for cutting tools in order to choose right material for the machining operation. Diffusion wear usually occurred in high speed machining which is due to higher cutting temperature caused by higher cutting speed. Other than that, wear by abrasion and wear processes between workpiece and cutting edge also happened in high speed machining. Table 2.1 summarized specified workpice materials and suitable cutting tools for high speed machining processes.

Table 2.1 Suitable cutting tools for specified workpiece material

Workpiece Material	Suitable Cutting Tools
Steel	• Coated and uncoated hard metals. • Cermets. • Ceramics. • Polycrystalline boron nitride (PKB).
Cast iron	• Hard metals. • Cermets. • Silicon nitride. • Cubical boron nitride (CBN). • Polycrystalline boron nitride (PKB).
Special alloys (high alloy steels, titanium and nickel-based alloys)	• Ceramics. • Hard metals. • Cermets. • Carbide. • High-speed steel (HSS).
Light metal alloys	• Polycrystalline diamond (PKD).
Copper alloys	• Hard metals. • Polycrystalline diamond (PKD).
Fiber reinforced plastics	• Carbide.
Graphite	• Polycrystalline diamond (PKD). • Polycrystalline boron nitride (PKB).

Source: Schulz and Moriwaki (1992)

- **Cutting edge geometry**

  Optimization of cutting edge geometry is necessary so that sufficient tool life and low forces can be achieved. Table 2.2 summarized the specified workpiece materials and cutting edge geometry.

Table 2.2 Specified workpiece materials and suitable cutting and draft angle

Workpiece Material	Cutting Angle	Draft Angle
Aluminum wrought alloys	12° to 15°	13° to 15°
Steel	0°	16°
Cast iron	0°	12°
Copper and copper alloys	8°	16°
Fiber reinforced plastics	>20°	15° and 20°

Source: Schulz and Moriwaki (1992)

- **Design of tools**

  Basic designing directives for fast-rotating tools:

  1. Using ductile materials.
  2. Minimize the notch effect which is depends on the necessary chip space.
  3. Minimize the notch effect which is depends on the cutting edge design.
  4. Provide for form-fit connections.
  5. Maintain low masses for all tool components.
  6. Arrange center of mass on small radii.

- **Interface between spindle and tool**

  Interface between spindle and tool and on the clamping system are important because both of these things must be able to operate under difficult condition. The design requirements that need to fulfill are:

  1. Rapid automatic tool change.

2. High performance functions.
3. Highest changing and repeating accuracy.
4. Small balance error.
5. High concentricity.
6. High run-out tolerance and position accuracy.
7. Reduced centrifugal force influenced by small radial dimensions and masses.

2.1.5 Machine Components

Schulz and Moriwaki (1992) explained that the concept of the machine and components must be equipped with sophisticated machine design. Important components of the machine as follow:

- **Machine base**
  To ensure the good dynamic performance this component must be made from polymer concrete because of economical and fabrication aspect.

- **High frequency main spindles**
  This is most essential component in high speed machine. It is created as a motor spindle with an integrated motor. The frequency regulated motor is always situated between the bearings.

- **Carriages**
  In order to ensure this component is lightweight, it is needed to:

  1. Select suitable construction material.
  2. Build by lightweight construction design.
  3. Use finite element analysis to determine optimal geometric dimension.
  4. Determination of the impacts on adjoining machine components.

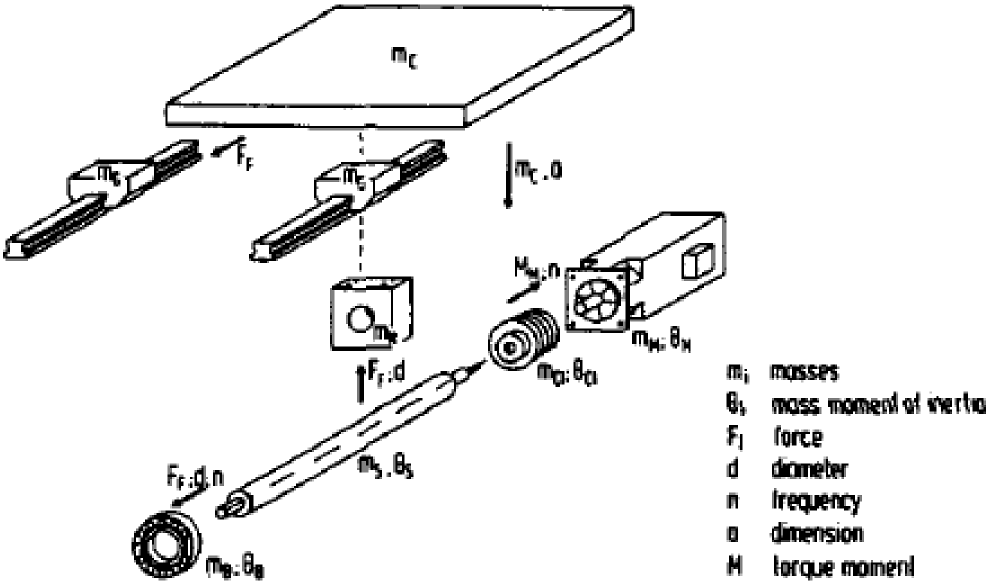

Figure 2.3 Effects of the lightweight construction moving components

Source: Schulz and Moriwaki (1992)

- **Guideways**

  Use antifriction guideways with roller or ball bearings because of high infeed speeds.

- **Feed drives**

  In order to reduce space allocations and increase infeed per spindle rotation it use multiple thread roller drives. This component must have good dynamic characteristics.

- **Controller**

  Use latest CNC controller system which offered large program capacity and high data processing rates.

- **Chip removal and coolant system**

  Chip removal systems must be able to remove high chip production per time unit during machining operation which is assisted by high pressure spray cooling systems.

- **Security devices**
  The cabin wall must be able to absorb the energy of a catapulting part without breaking due to high speed operation.

2.1.6 Applications

Generally, there are many industries that gain benefits in application of high speed machining such as aerospace, automotive, mould and die, electrical and electronic, biomechanical and medical, also other industries (Pasko et al. 2002 and Schulz and Moriwaki, 1992).

This is because the characteristic of high speed machining which can produce products more efficient, accurate, and quality if compare to conventional machining. It is also can reduce manufacturing time and cost because of reduction in machining processes compare to traditional methods.

Table 2.3 briefly describe the characteristic, applications, and examples of high speed machining in manufacturing sector around the world. As seen on Table 2.3, high material removal volume in time is required in aerospace and tool and die making industry. This characteristic is applied in light metals and steels and cast iron.

High surface quality is necessary to produce precise and special components in tool and die making, precision machining and optical industry. Then, low cutting force is required in aerospace, automotive industry and household appliances in order to produce components that have thin walled.

Other than that, high exciting frequency and heat dissipation through chips characteristics are necessary in precision machining and optical industry which applied vibration-free and distortion-free machining process.